LHC Upgrade

Kai Hock

1. The LHC
2. Motivation and Activities
3. The Science Case
4. Technical Issues and Challenges
5. Opportunities for us
6. Scale of project
7. UK support

Main Sources

CERN LHC website - the LHC
http://public.web.cern.ch/Public/en/LHC/LHC-en.html

CARE-HHH website - LHC upgrade
http://care-hhh.web.cern.ch/CARE-HHH/default.html

CERN Courier website - non technical articles
http://cerncourier.com/cws/latest/cern

The LHC

Principal goal

- exploration of a completely new region of energies and distances
    - the tera electron volt scale and beyond.

Main objectives

- search for the Higgs boson
- whatever new physics may accompany it – supersymmetry, extra dimensions
- perhaps above all – to find something that the theorists have not predicted.

Ellis (2007)

The accelerator complex

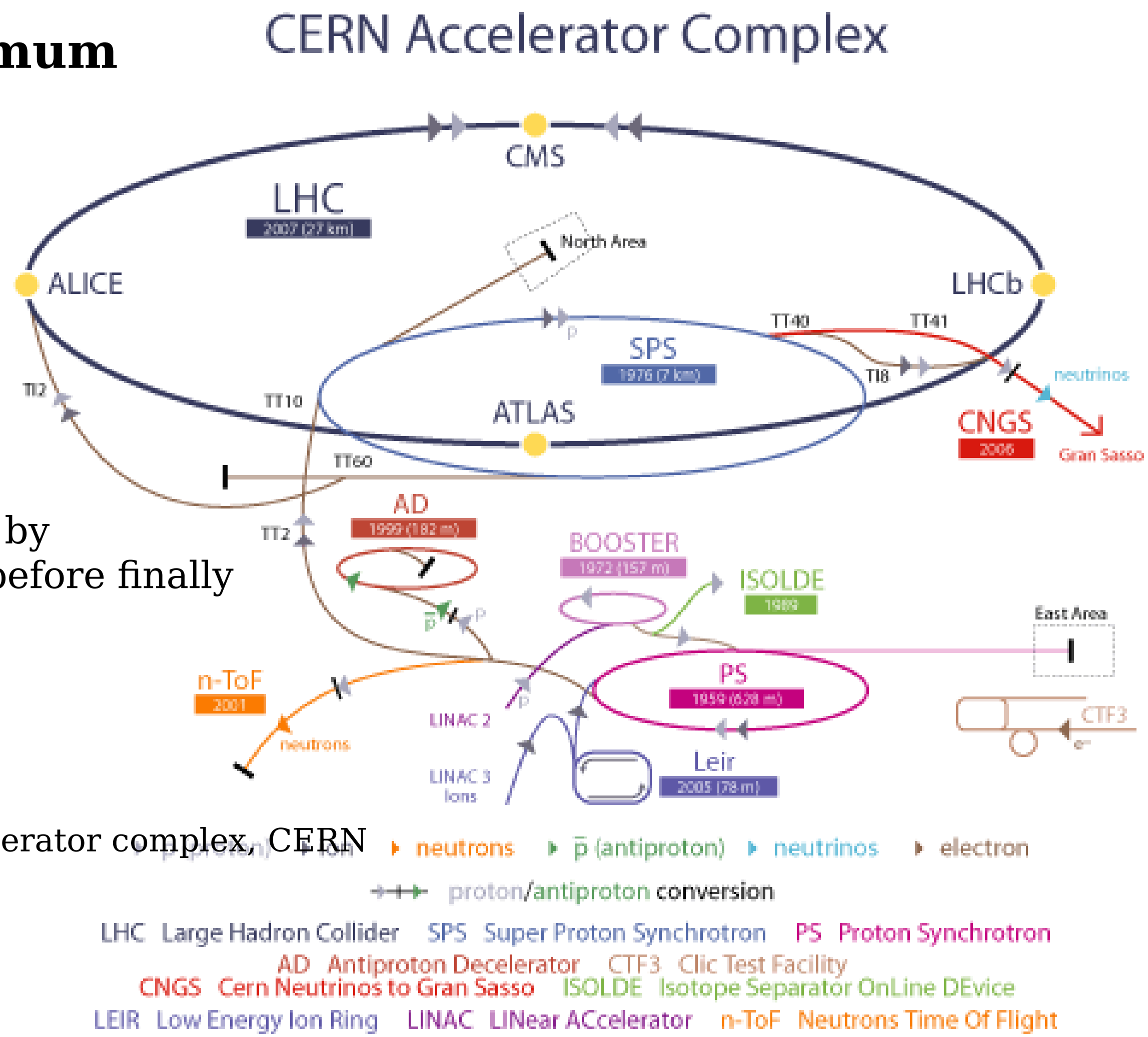
CERN's accelerator complex is a succession of particle accelerators that can reach increasingly higher energies.

A proton's journey to maximum acceleration

Protons are obtained by removing electrons from hydrogen atoms.

They are injected from

the linear accelerator (LINAC2) into
the PS Booster, then
the Proton Synchrotron (PS), followed by
the Super Proton Synchrotron (SPS), before finally reaching
the Large Hadron Collider (LHC).



The accelerator complex, CERN (2007)

Facts and figures

The largest machine in the world...

The precise circumference of the LHC accelerator is 26 659 m, with a total of 9300 magnets inside.

All the magnets will be pre-cooled to -193.2°C (80 K) using 10 080 tonnes of liquid nitrogen, before they are filled with nearly 60 tonnes of liquid helium to bring them down to -271.3°C (1.9 K).

The fastest racetrack on the planet...

At full power, trillions of protons will race around the LHC accelerator ring 11 245 times a second, travelling at 99.99% the speed of light.

Two beams of protons will each travel at a maximum energy of 7 TeV (tera-electronvolt), corresponding to head-to-head collisions of 14 TeV.

The emptiest space in the Solar System...

The internal pressure of the LHC is 10^{-13} atm, ten times less than the pressure on the Moon!

The most powerful supercomputer system in the world...

The data recorded by each of the big experiments at the LHC will fill around 100 000 DVDs every year.

To allow the thousands of scientists scattered around the globe to collaborate on the analysis over the next 15 years (the estimated lifetime of the LHC), tens of thousands of computers located around the world are being harnessed in a distributed computing network called the Grid.

Facts and figures, CERN (2007)

Motivation for LHC Upgrade

By about 2014, the quadrupole magnets in the interaction regions will be nearing the end of their expected radiation lifetime, having absorbed much of the power of the debris from the collisions.

There will also be a need to reduce the statistical errors in the experimental data, which will require higher collision rates and hence an increase in the intensity of the colliding beams - in other words, in the machine's luminosity.

An improved luminosity will also increase the physics potential, extending the reach of electroweak physics as well as the search for new modes in supersymmetric theories and new massive particles, some of which could be manifestations of extra dimensions.

Scandale and Zimmermann (2005)

Current Activities

The European Community has supported the High-Energy High-Intensity Hadron-Beams (HHH) Networking Activity, which started in March 2004 as part of the Coordinated Accelerator Research in Europe (CARE) project.

HHH has three objectives:

- to establish a roadmap for upgrading the European hadron accelerator infrastructure;

- to assemble a community capable of sustaining the technical realization and scientific exploitation of these facilities;

- to propose the necessary accelerator R&D and experimental studies to achieve these goals.

Scandale and Zimmermann (2005)

CARE-HHH Network structure

The HHH Network is structured into three workpackages.

Advancements in Accelerator Magnet Technologies (AMT)
keywords: stability and quench limit of LHC insertion magnets, pulsed magnets for LHC and GSI accelerator complex upgrade, magnets for booster ring, high field magnet design, optimisation of the overall cost

Novel Methods for Accelerator Beam Instrumentation (ABI)
keywords: tools and diagnostic systems for luminosity, wire for beam-beam compensation, advanced transverse beam diagnostics, feedback loops for orbit, chromaticity and coupling, advanced beam halo diagnostics, remote diagnostics and maintenance of instrumentation

Accelerator Physics and synchrotron Design (APD)
keywords: Interaction Region design for LHC luminosity upgrade, optics design for booster synchrotrons, impedance calculations, structured list of intensity limits, electron cloud effects, beam measurements and advanced theoretical studies

Participating institutes

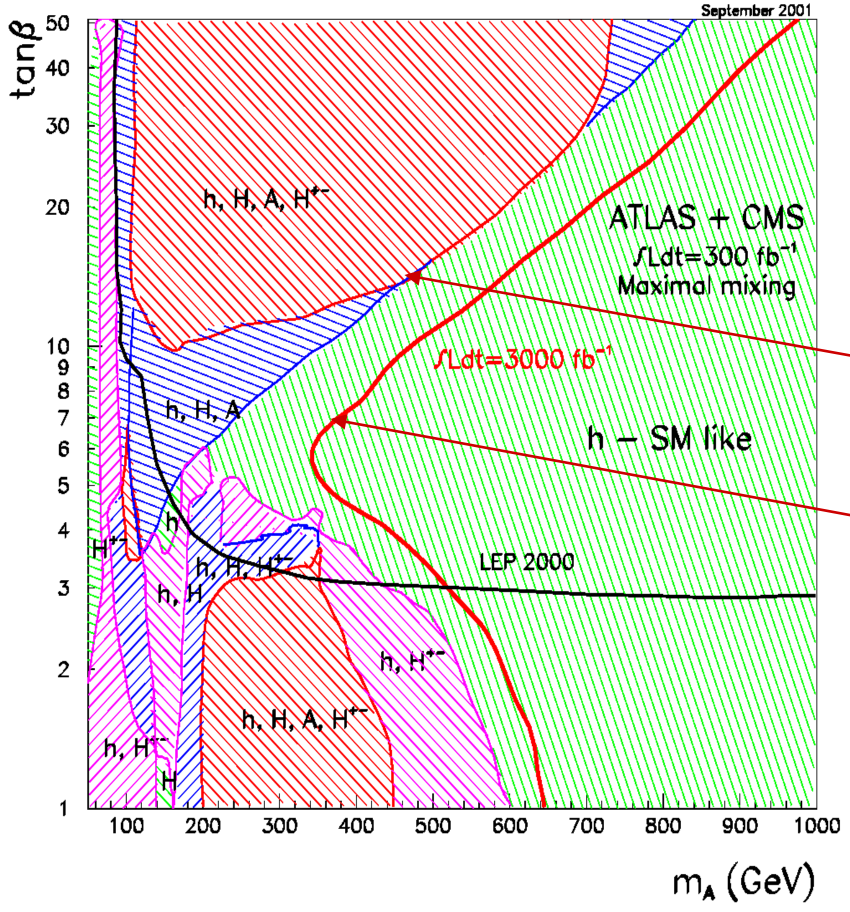
The following organizations and associated institutes contribute to the CARE-HHH Network (and specifically to the workpackages indicated in parentheses):

- CEA (AMT)
- GSI (AMT, ABI, APD)
- DESY (ABI, APD)
  - FZK (AMT)
  - TEMF (APD)
- INFN (AMT, APD)
- TEU (AMT)
- WUT (AMT)
- CSIC (APD)
- CERN (AMT, ABI, APD)
  - CRPP (AMT)
  - ENEA (AMT)
  - TUBE (APD)
  - ESRF (ABI)
  - UPSA (ABI)
  - BNL (AMT, ABI, APD)
  - FNAL (AMT, ABI, APD)
  - LBNL (AMT, ABI, APD)
  - JINR (AMT)
  - IHEP (APD)
  - KEK (AMT, APD)
- PSI (ABI)
- CCLRC (AMT)

Science Case: Physics potential of the LHC at 10^{35} cm^{-2} s^{-1}

(SLHC)

Improved reach for Higgs bosons



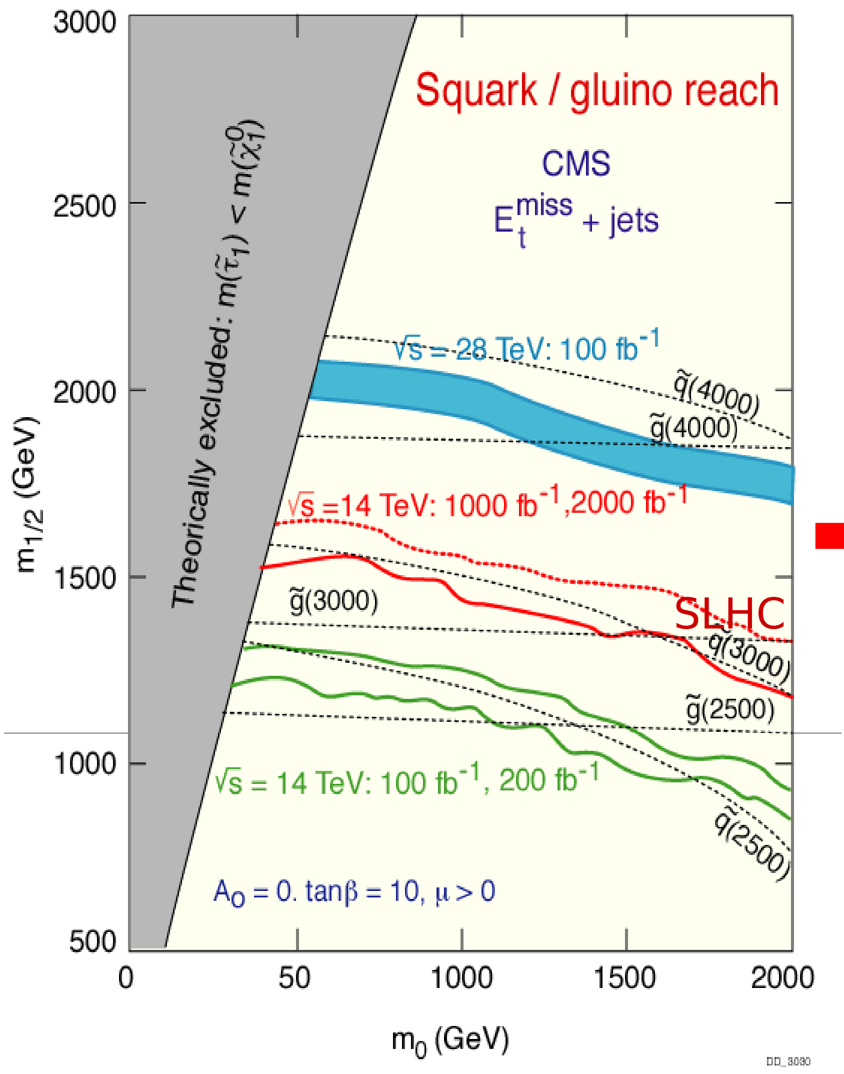
LHC contour, 300 fb^{-1}

SLHC contour, 3000 fb^{-1}

at least one heavy Higgs discoverable up to here

Denegri (2004)

SUSY at SLHC - mass reach



Higher integrated luminosity brings an obvious increase in mass reach in squark, gluino searches, i.e. in SUSY discovery potential;

➡ with SLHC the SUSY reach is increased by ~ 500 GeV, up to ~ 3 TeV in squark and gluino masses

Denegri (2004)

Technical Issues

The basic proposal for the LHC upgrade is, after seven years of operation, to increase the luminosity by up to a factor of 10, from the current nominal value of 10^{34} cm^{-2} s^{-1} to 10^{35} cm^{-2} s^{-1}.

Robert Aymar, director-general of CERN reviewed the priorities of the laboratory until 2010, mentioning among them the development of technical solutions for a luminosity upgrade for the LHC to be commissioned around 2012-2015.

The upgrade would be based on:

- a new linac, Linac 4, to provide more intense proton beams, together with

- new high-field quadrupole magnets in the LHC interaction regions to allow for smaller beam sizes at the collision points

- It would also include rebuilt tracking detectors for the ATLAS and CMS experiments.

Scandale and Zimmermann (2005)

The goals

	tentati veplan ning	*goal*
Phase I: LHC+ (or SLHC1)	2012	Triplet consolidation for high integrated luminosity; Luminosity $\times$1 to $\times$ 2; ***no interference with detectors***
Phase II: SLHC (or SLHC2)	2016	Luminosity $\times$ 10:
Phase III: LHC-D	2020-25	energy doubler or tripler

Koutchouk (2007)

The strategies

Two main tracks:

- Luminosity increase **by increasing the beam current**
- Luminosity increase **by lowering β***

Koutchouk (2007)

Increase of beam current

Challenges: **<u>new beam dynamics</u>:** novel beam-beam regime not experienced at this level of performance; higher peak beam current coupling to machine elements, sophisticated rectangular beam distribution; **<u>machine protection:</u>** higher bunch/beam power; higher collimator robustness required; **<u>radiation protection:</u>** protection to be re-assessment when exceeding the ultimate beam current in the LHC. **<u>injectors:</u>** new beam preparation; injectors' upgrade for full operational performance: Linac4, PS2, SPS improvement.

Koutchouk (2007)

Decrease of beta*

Merits: modification of LHC only in IR's with no consequence for the global machine; <u>no beam current increase beyond the agreed LHC & INB programs</u> (collimation, machine and radiation protection); same beam dynamics mode and operations strategy; easy luminosity leveling, expected faster build-up of performance related to a lower complexity; compatible with 25 and 50 ns spacing (with reduced performance by 2), mild upgrade of injectors but benefits from an injector upgrade program.

Challenges: <u>**installation of dipoles deep inside the detectors**</u>, higher chromatic aberrations, a few encounters at a reduced beam separation, lower integrated luminosity per run.

Koutchouk (2007)

The simulation challenge

The (HHH-2004) workshop established a list of priorities and future tasks for the various simulation needs:

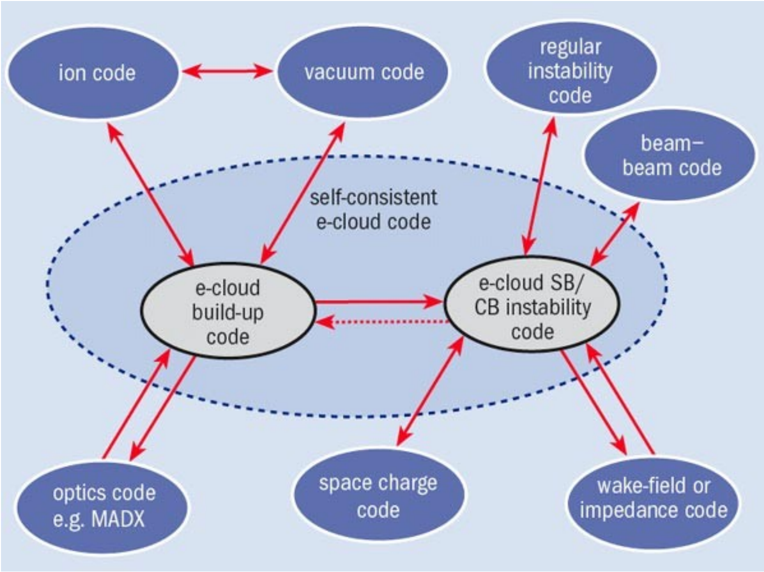
Benchmarking of codes to increase confidence in their predicative power.

Creating an experimental data bank and a set of standard models, for example for vacuum-chamber surface properties, which would ease future comparisons of different codes.

New computing issues, such as parallelization, modern algorithms, numerical collisions, round-off errors and dispersion on a computing Grid.

The simulation codes being developed should support all stages of an accelerator project that has shifting requirements; communication with other specialized codes is also often required.

Codes should have toolkits and a modular structure as well as a standard input format, for example in the style of the Methodical Accelerator Design (MAD) software developed at CERN.



Schematic for a universal simulation code, emerging from a self-consistent electron-cloud core.

LHC Luminosity Upgrade including Injectors Upgrade: workpackages and tentative milestones

accelerator	WorkPackage	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	after 2015
LHC Main Ring	Accelerator Physics											
	High Field Superconductors											
	High Field Magnets											
	Magnetic Measurements											
	Cryostats											
	Cryogenics: arcs, IR magnets, RF											
	RF and feedback											
	Collimation&Machine Protection											
	Beam Instrumentation											
	Beam Dump											
	Power converters											
LHC Injectors & Transfer Lines	Accelerator Physics											
	Low Loss Superconductors											
	Pulsed SC Magnets											
	Magnetic Measurements											
	Cryostats											
	Cryogenics: magnets & RF											
	Vacuum system											
	RF and feedback											
	Collimation&Machine Protection											
	Beam Instrumentation											
	Kickers & Beam Dump											
	Power converters											
	Tentative Milestones: Beam Dynamics and LHC Main Ring	Beam-beam compensation test at RHIC	SPS crystal collimation test	LHC collimation tests	LHC collimation tests	Install phase 2 collimation	LHC tests: collimation & beam-beam			Upgrade LHC cryogenic system	new IR magnets, RF, cryogenics, bb-compensation, collimation and beam dump	
	Tentative Milestones: Injectors Upgrade			Super-SPS dipole prototype with LHC cable	Low Loss SC cable ready	Super-SPS dipole prototype with low loss cable	Super-SPS quadrupole prototype with low loss cable				new injectors and transfer lines	
	Other Tentative Milestones	Crab cavity test at KEKB	Low-noise crab cavity test at RHIC	LHC Upgrade Conceptual Design Report		LHC Upgrade Technical Design Report	Nominal LHC luminosity 10^34			Ultimate LHC luminosity 2.3x10^34		LHC luminosity approaching 10^35

R&D - scenarios & models	
specifications & prototypes	
construction & testing	
installation & commissioning	

LHC Injectors Upgrade scenario: peak luminosity ~10^35/(cm^2 sec)
Integrated luminosity 9 x nominal ~ 600/(fb*year) assuming 5 h turnaround time
new high energy injectors based on pulsed superconducting magnets: Super-ISR and Super-SPS (1 TeV)
new transfer lines to inject at 1 TeV into the LHC
new RF systems, cryogenics, power converters, and kickers for Super-ISR and Super-SPS
new BPM system in the LHC main ring for bunch spacing smaller than nominal 25 ns
collimation beyond phase 2, upgraded cryogenics, and new beam dump system to exceed ultimate intensity
beam-beam compensation mandatory to fully exploit injector upgrade
upgrade of low energy injectors (Linac 4 and possibly new PS) is assumed

F. Ruggiero (2005)

Opportunities for us

Accelerator code development

- Merlin, universal parser
- nonlinear dynamics, parallel computing, optimisations
- benchmarking, predictive power

Impedance and Wake Field

- rf cavity, vacuum components, beam pipes

Collective Instabilities

- single bunch, multi-bunch, long/short range wake field

Scale of project

The LHC (Intensity) Upgrade

Possibility to get major luminosity increases for modest costs

- Phase 0, no extra machine costs: Luminosity multiplied 2.3 times
  - Increase number of bunches to max
  - Also increase dipole field to max. (9 T)
- Phase 1, small costs: Luminosity multiplied 2 times
  - from new low-beta insertions with ß*=0.25 m
  - Crab cavities (better angle of bunches at collision)
  - New RF cavities with higher harmonics
- Phase 2: significant costs
  - Upgrade many things and use the new LHC RF to double the number of bunches (12.5 ns) Luminosity multiplied 2 times
  - Super SPS (most costly) ...better magnets, new SPS RF, new SC linac; inject at 1 TeV... Luminosity multiplied 2 times

Ruggiero (2005), Oram (2006), LHC Wikipedia (2008)

What about an LHC energy upgrade?

- Whereas a luminosity upgrade is relatively cheap, quick and non-disruptive, an energy upgrade is not an upgrade — it is an entirely new collider — and, it will probably need a new injector, too

- The best performance from Nb_3Sn magnets will result in only a 70% increase in energy

- The R&D to develop robust and cost-effective magnets at the highest field will take a long time and be very costly.

A staged VLHC is a better path.

- Higher energy per $ or €, even in its initial stage

- Upgradeable to > 200 TeV (cm)

Limon (2003)

UK support

Facts

UK scientists are leaders in several key scientific and technological areas in the LHC project. Funding has been approved for UK scientists to take part in the four LHC experiments

STFC provides research grants and studentships to UK institutes working on the LHC project, and funds the UK membership of CERN.

The cost of building the LHC will be £2.1 billion over 13 years, of which, the UK's contribution will be around 16%.

STFC (24/9/2007)

Rumours

"The cuts will affect the LHC in that particle physics groups will get hammered in general, " says Dr Brian Cox of Manchester University, one of the team who will work on the new atom smasher.

"Also the LHC upgrade plans are now much less certain to be funded in the UK."

Daily Telegraph (27/12/2007)

Our Case

1. **How good is the science case?**

**good; - increases chance of finding Higgs

2. **What are the technical issues and challenges?**

***many fascinating problems - a new physics regime

3. **What are the opportunities for us?**

***plenty of work available, well-matched to our abilities; - many aspects of accelerator physics involved

4. **What is the scale of the project, and the likelihood of UK support?**

**expensive but feasible, and/or not on the UK science agenda ; - STFC funds the LHC

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Stephen Hawking joins attack on science cuts   By Roger Highfield, Science Editor
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Page last updated: 24 September 2007 by Andy Mckinna